SCHEDULING OF BATCH PROCESSORS IN SEMICONDUCTOR MANUFACTURING – A REVIEW

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Abstract— In this paper a review on scheduling of batch processors (SBP) in semiconductor manufacturing (SM) is presented. It classifies SBP in SM into 12 groups. The suggested classification scheme organizes the SBP in SM literature, summarizes the current research results for different problem types. The classification results are presented based on various distributions and various methodologies applied for SBP in SM are briefly highlighted. A comprehensive list of references is presented. It is hoped that, this review will provide a source for other researchers/readers interested in SBP in SM research and help simulate further interest.

Index Terms— Scheduling, Batch Processor, Semiconductor Manufacturing System, Review, Classification

I. Introduction

The need for literature review papers focusing entirely on one particular aspect of scheduling theory has been recognized and a wealth of survey papers have been published to provide detailed information on a particular aspect of scheduling research. For example, Gordon et al. (2002), Sen and Gupta (1984) and Cheng and Gupta (1989) provide a framework for studying due date related scheduling problems; Allahverdi et al. (1999) review scheduling research involving setup consideration, Drexl and Kimms (1997) survey the lot sizing and scheduling issues; and Sox et al. (1999) review the stochastic lot scheduling problem. In this paper we have attempted to review batch scheduling because job scheduling on a batch processing system is an important issue in the manufacturing industry [Deng et al. (1999)].

Batching jobs in a manufacturing system is a very common policy in most industries. The main reasons for batching are avoidance of set ups and/or facilitation of material handling. Batching occurs in two versions: serial batching and parallel batching. In serial batching, jobs may be batched if they share the same setup on a machine and one job is processed at a time. In parallel batching, several jobs can be processed as a batch (that can possibly be grouped up to the capacity of the machine) simultaneously on a machine at one time. In the literature, the "parallel batching" is termed as "scheduling of batch processor (SBP) or scheduling of batch processing machine".

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Potts and Van Wassenhove (1992), Albers and Bruckers (1993), Webster and Baker (1995), Brucker et al. (1998) and Potts and Kovalyov (2000) provide a good analysis of both types of scheduling with batching. Recently, Baptiste (2000) studied the problem of scheduling jobs with different release times and equal processing times on both situations: serial and parallel batching machines. In this paper, we provide a literature review to the SBP and not attempted to review a serial batching scheduling problem. Further, though batch processors are encountered in many different environments, the literature review is focused to semiconductor manufacturing (SM) only..

A batch processor (BP) is a procesor that can operate on a batch of jobs (that can possibly be grouped up to the capacity of the machine) simultaneously, with common beginning and end times (unlike a discrete processor which processes one job at a time). Once the process begins, the BP cannot be interrupted. Thus, no job in a batch can be released from the BP or added to the BP until the processing of the entire batch is completed. We define the batch as the set of jobs that are processed together. We call the number of jobs in a processing cycle the batch size.

The remainder of this paper is organized as follows. In section 2, we provide a brief overview of semiconductor manufacturing system. A broad classification of SBP in SM problems and the classification results is given in Section 3. In section 4, a classification of solution methodologies based on the literature review is presented. Finally, section 5, presents the summary and conclusion of this survey.

II. SEMICONDUCTOR MANUFACTURING AND BATCH PROCESSORS

Semiconductor manufacturing (SM) is one of the fastest growing industries in the world today (Oey and Mason (2001)). The market demand for semiconductor is increasing because of the diverse market focusing on integrated circuits for networking, storage components, telecommunications and/or wireless, consumer, computer and storage systems that have become necessary tools of today. Further, SM is one of the most complex production systems due to the intricate manufacturing processes involved as well as to the range of product types [Huang and Lin (1998)].

The manufacturing processes involved in SM system is being grouped by many researchers into four stages, which are termed wafer fabrication, wafer probing, device assembly, and device testing. For a detailed description of semiconductor manufacturing processes, see Uzsoy et al. 1992 and Knutson et al. 1999. The four phases of SM system are carried out separately in different work centers. These four stages further grouped into two categories. That is, wafer fabrication and wafer probing are referred to as frond-end manufacturing operations. Device-assembly and device testing are referred to as backend manufacturing operations.

Scheduling is very important in the semiconductor manufacturing because there is a high competition between semiconductor manufacturers. Therefore, the timely completion of order is a high priority and this could be achieved with proper scheduling methodologies of various processes in the SM.

All SM typically involve numerous batch-processing operation, e.g. oxidation, diffusion, deposition, etching, e-beam writing and heat-treatment of wafer fabrication, baking of wafer probing and burn-in of device testing. These operations plan an important role in determining how the system performs in terms of throughput, WIP and cycle time. They generally add variability into a system because items wait to form a batch and upon service completion multiple items are released to downstream operations [Fowler et al. (2002)]. Further, effective scheduling of many batch processors in SM system is important in terms of improving the due date compliance of the whole SM system and also for significant reduction in the overall production time due to their long processing times compared to other processes in the specific shop.

III. REVIEW ON SBP IN SM

SBP in SM can be broadly classified according to the two broad groups of semiconductor manufacturing process, namely Front-end process and back-end process. Within these groups of SM process, the SBP can further be classified into (a) considering the BP in isolation from a large manufacturing line, as a single work center problem, (b) considering one or more upstream or downstream operation along with BP, and (c) considering a complex job shop or flow shop with reentrant and BP. In addition to these two series of classifications, the SBP is classified into deterministic scheduling and stochastic scheduling based on the data availability.

Using the three series of classifications as mentioned above, it is possible to group the research on SBP in SM problems into 12 different categories [2 x 3 x 2]. A quick research references on the published research based on the 12 categories is given in Table 1. Further, it is to be noted that 1986 was chosen as a starting year for our search, because, Ikura and Gimple (1986) are usually considered as the first researchers who studied the problem of scheduling a single BP with a single job family from a deterministic scheduling perspective [Fanti et al. (1996) and Azizoglu and Webster (2001)].

Classification of SBP in SM			References
Phase in SM	Processor for Scheduling	D/S	
Front - End	BP : Single work center	D	2, 7, 27, 38, 39, 47, 48, 52, 62, 72, 78, 91
		S	5, 34, 40, 41, 83
	BP: Downstream/ Upstream	D	1, 53, 63, 79, 81, 84, 85, 88,
		S	44, 74
	BP-Reentrant	D	22, 60, 66
		S	NIL
Back - End	BP : Single work center	D	6, 12, 15, 16, 17, 20, 24, 25, 26, 32, 33, 45, 46, 49, 50, 51, 55, 56, 57, 58, 59, 68, 75, 82, 86, 87, 90, 92, 93, 96, 98, 104, 105
		S	5, 42, 54, 100
	BP: Downstream/ Upstream	D	1, 14, 21, 63, 69, 84
		S	NIL
	BP-Reentrant	D	NIL
		S	NIL

D: Deterministic **S:** Stochastic

Table 1: Classification of SBP in SM and Published Research References

Table 1 reveals that there exists a many potential areas worthy of further research. The review also shows that an increasing volume of SBP research has been conducted mainly in the back end operations of SM process, particularly on scheduling burn-in ovens. Further, it is observed from the review that only one paper discuss on scheduling baking equipment of wafer probing area [Huang and Lin (1998)] and only one paper on scheduling E-beam writers [Hung, 1998] of wafer fabrication area.

During the process of reviewing SBP, focusing on SM process, it is observed that only very few studies on SBP on other manufacturing systems such as aircraft industries [Zee et al. (1997) and (2001)] steel casting industries [Mathirajan (2000)], shoe manufacturing [Fanti et al. (1996)] and metal industries [Dupont and Dhaenens-Flipo (2002), Dobson and Nambimadom(2001), and Ram and Patel (1998)] were carried out.

Classification Results:

This review was based on a study of journals and web-based available conference materials, thesis materials, lecture notes and working papers. A total of 81 articles were classified according to the scheme proposed in this paper and these are related to SBP in semiconductor manufacturing only. We analyzed the identified articles by classification-topic area, year of publication, and percentage of the total number of articles in the grouped category of journals.

The distribution of articles by classification scheme: The distribution of articles according to the classification scheme, proposed in this paper is shown in Table 2.. The most heavily published research area is in the area of back-end, particularly the deterministic scheduling of burn-in ovens. Followed with this is in the area of front-end, particularly the deterministic scheduling of oxidation/diffusion furnaces. Many real complexity issues involved in SM could be the reasons for not having much research in the other combination of the classification scheme.

SM-Phase	Data-Type	BP considered for scheduling	No. of Articles	%
Front-end	D	AS a single machine	12	14.1
	D	With upstream/downstream processor(s)	8	9.4
	D	With reenter situation	3	3.5
Front-end	S	AS a single machine	5	5.9
	S	With upstream/downstream processor(s)	2	2.4
	S	With reenter situation	NIL	
Back-end	D	AS a single machine	33	38.8
	D	With upstream/downstream processor(s)	6	7.1
	D	With reenter situation	NIL	
Back-end	S	AS a single machine	4	4.7
	S	With upstream/downstream processor(s)	NIL	
	S	With reenter situation	NIL	
OTHERS [Both serial and parallel batching together discussed, proving NP-hardness, etc.]			12	14.1

Note: Here the total is 85 (and not 81). This is due to 4 studies, Which are common to both Front-end and Back-end of SM.

Table 2 : Distribution of research articles w.r.t. classifications proposed

Distribution of the year of publication: The distribution of articles published with the class interval of two years is shown in Figure 1 from 1986 to 2002 (part only). Class of Interval of two years is selected because any articles takes about 1 to 2 years on the average to get published by the repited/international journals. From the figure 1 it is clear that there is a limited research outputs before 1992 but the number of journal articles has some increased trend from 1995 onwards.

Percentage of total articles in grouped category of journals: Number of articles in all the published journals is computed and the same is shown in Table 3. In addition to conference proceeding, working papers and thesis, research papers on SBP appeared on 22 journals. Further, the research articles reviewed are grouped with respect to subjects: Operations Research (OR), Industrial Engineering (IE), Manufacturing (MANUF), Production and Operations Management (POM), Scheduling & Logistics (S&L) and Web-based articles [WEB]. Distribution of articles based on this grouping is shown in Figure 2.

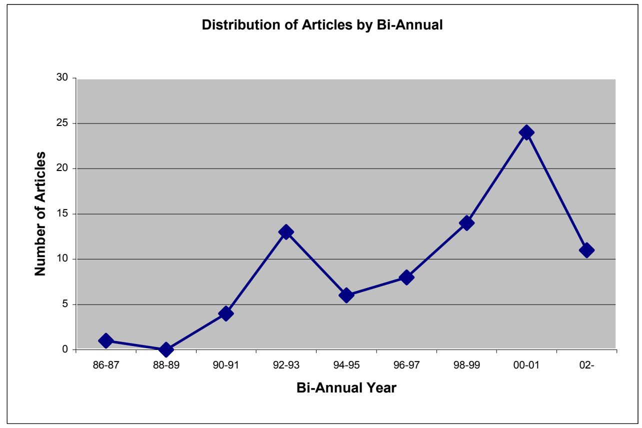

Figure 1: Distribution of Articles by Bi-Annually

Subject Code	Journal	No. of Articles
IE	Computers and Industrial Engineering	1
IE	International Journal of Industrial Engineering	1
IIE	IIE Transactions	8
MANUF	Journal of Electronics Manufacturing	1
MANUF	Journal of Manufacturing Systems	2
MANUF	IEEE Transactions on Semiconductor Manufacturing	5
OR	Belgian Journal of Operations Research. Statistics and Computer Science	1
OR	Engineering Optimization	1
OR	Journal of Operational Research Society	1
OR	Mathematical Methods of Operations Research	1
OR	Prabability in the Engineering and Informational Science	1
OR	Annals of Operations Research	2
OR	Discrete Applied Mathematics	3
OR	Computers and Operations Research	3
OR	Operations Research Letters	4
OR	European Journal of Operational Research	5
OR	Operations Research	4
POM	International Journal of Production Economics	1
PON	Production and Operations Management	1
POM	International Journal of Production Research.	11
S&L	Naval Research Logistics.	3
S&L	Journal of Scheduling	4
WEB	http://www-leibniz.imag.fr/LesCahiers/Cahier45/CLLeib45.pdf	1
WEB	Thesis - Phd	1
WEB	Working Paper	1
WEB	Springer-Verlag Berlin Heidelberg 2002 [Lecture notes in Computer Science]	6
WEB	Proceedings	8

Table 3: Distribution of Articles w.r.t. Journals/Proceedings

Figure 2 shows that the OR related journals has by far the most articles related to SBP. Followed to OR related journals, the web-sources (conference papers and lecture notes on batch processors) and production and operations management sources are having more papers on SBP. Surprisingly, the number of papers appeared related to manufacturing journals is very less and this may be due to the fact that many research studies are not based on real-applications and/or not implemented in the respective SBP system!

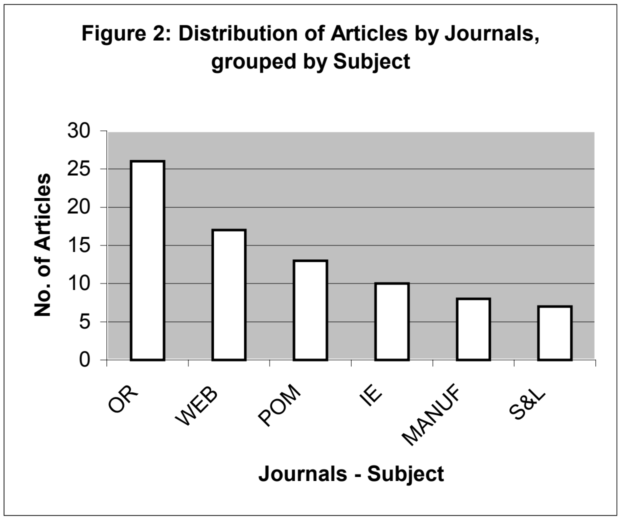

Figure 2: Distribution of Articles by Journals, grouped by Subject

IV. SOLUTION METHODOLOGIES

From the scheduling methodology published in the literature with special reference to SM could be grouped broadly into exact approach, approximate approach and simulation approach. Dynamic programming (DP) is the one mostly proposed by many researchers [Lee et al. (1992), Dupont and Jolai (1997c), Hung (1998), Mehta and Uzsoy (1998), Sung et al. (2002b)] as an exact approach for scheduling batch processors in the SM. The DP approach guarantee global convergence as long as problems are small, particularly for a simple version of scheduling a single BP with single family of jobs. Further, in general, DP is limited to dealing with problems with relatively few constraints [Neufville, 1990]. Few researchers proposed integer programming approaches for scheduling batch processors in SM [Dobson and Nambimadom (1994), Sung and Choung (2000)]. Since the scope for mathematical programming is limited because of the complexity of the scheduling BP in the SM, many researchers are continuously putting lot of efforts in developing heuristic approaches and simulation approaches.

The heuristics proposed so far for scheduling batch processors can be classified into (a) construction based heuristic approaches and (b) improvement heuristics. Almost all the construction-based heuristics are mostly on greedy in nature and recently researchers started to propose the meta heuristic (improvement heuristics) such as genetic algorithm [Wang and Uzsoy (2002) and Skinner and Mason (2002)] and neural network approach [Sung and Choung (1999)]. Few researchers are effectively coupling decision algorithms (mostly heuristic algorithms) and simulation package, which is termed in the literature as simulation based scheduling, for scheduling batch processors in the SM [Oey and Mason (2001), Mason et al. (2002), Solomon et al. (2002)]. The main drawback of these approaches is that the decision tend to be myopic, that is, it does not consider relevant information that may have an impact on the schedule that is drawn up which occurs elsewhere on the shop floor [Suresh and Chaudhuri, 1993]. But the advantage is that these approaches are expected to provide almost all the time a better schedule than the manual way of scheduling.

V. SUMMARY AND CONCLUSIONS

An extensive literature survey was attempted to review SBP in SM related articles from various journals that are possible outlets for SBP research in SM and also available web-based documents. This resulted in the identification of 81 articles related to SBP in SM, published between 1986 and 2002 (part only). It is observed that the number of published paper between the period 1986 and 1991 is very meager (only two papers), so we can conclude that there are 79 articles appeared in various journals and web-based documents in the area of SBP in SM. That is, on an average about 7 or 8 articles appeared in journals/web-based sources about SBP in SM, which shows clearly that SBP in SM is an important research area.

It is observed from the review that only a few papers appeared between the period 1992 and 2002 in the manufacturing related journals, particularly in IEEE journal on Semiconductor Manufacturing. This may be due to the nature of articles such as highly/partially theoretical papers! or the articles are not focused to application/implementation oriented!.

Last, but not least that this review cannot be claimed to be exhaustive, but it does provide reasonable insights into the state-of-the-art research on SBP in SM.

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REFERENCES

1. Ahmadi, J.H., Ahmadi. R.H., Dasu, S., and Tang, C.S., 1992. Batching and scheduling jobs on batch and discrete processors. Operations Research 39 (4), 750-763.
2. Akcali, E., Uzsoy, R., Hiscock, D.G., Moser, A.L., and Teyner, T. 2000. Alternative loading and dispatching policies for furnace operations in semiconductor manuafcturing: A comparison by Simulation. Proceedings of the 2000 winter simulation conference.
3. Albers, S. and Brucker, P., 1993. The complexity of one-machine batching problem. Discrete Applied Mathematics 47, 87-107.

4. Allahverdi, A., Gupta, J.N.D., and Aldowaisan, T., 1999. A review of scheduling research involving setup considerations. Omega, International Journal of Management Science 27, 219-239.
5. Avramidis, A.N., Healy, K.J., and Uzsoy, R. 1998. Control of batch processing machine : a computational approach. International Journal of Production Research 36, 3167-3181.
6. Azizoglu, M. and Webster, S., 2001. Scheduling a batch processing machine with incompatible job families. Computers and Industrial Engineering 39, 325-335.
7. Azizoglu, M. and Webster, S., 2000. Scheduling a batch processing machine with non-identical job-sizes. International Journal of Production Research 38 (10), 2173-2184.
8. Baptiste, Ph., 2000. Batching identical jobs. Mathematical Methods of Operations Research 52, 355-367.
9. Brucker, P., Gladky, A., Hoogeveen, H., Kovalyov, M.V., Potts, C.N., Tautenhan, T., and Van De Velde S.L., 1998. Scheduling a batching machine. Journal of Scheduling 1, 31-54.
10. Boudhar, M., 2002. Scheduling on a single batch processing machine with bipartite compatibility graphs. http://www-leibniz.imag.fr/LesCahiers/Cahier45/CLLeib45.pdf
11. Boudhar, M. and Finke, G., 2000. Scheduling on a single batch machine with job compatibilities. Belgian Journal of Operations Research. Statistics and Computer Science 40, 69-80.
12. Cai, M.-C., Deng, X., Feng, H., Li, G., and Liu, G. 2002. A PTAS for minimizing total completion time of bounded bacth scheduling. IPCO'2002, LNCS 2337, 304-314 [Cook, W.J. and Schulz, A.S. (Eds.)], Springer-Verlag Berlin Heidelberg 2002.
13. Chambers, R.J., Carraway, R.L., Lowe, T.J., and Morin, T.L., 1991. Dominance and decomposition heuristics for single machine scheduling. Operations Research 39, 639-647.
14. Chandra, P. and Gupta, S., 1997. Managing batch processors to reduce lead-time in a semiconductor packaging line. International Journal of Production Research 35 (3), 611-633.
15. Chandra, P., and S. Gupta., 1992. An Analysis of a last-station-bottleneck semiconductor packaging line. Research Working Paper: 92-10-13, Faculty of Management, McGill University.
16. Chandru, V., Lee, C.-Y., and Uzsoy, R., 1993a. Minimizing total completion time on a batch processing machine. International Journal of Production Research 31, 2097-2121.
17. Chandru, V., Lee, C.-Y., and Uzsoy, R., 1993b. Minimizing total completion time on a batch processing machine with job families. Operations Research Letter 13, 61-65.
18. Chen, B., Deng, X., and Zang, W. 2001. On-line scheduling a batch processing system to minimize total weighted job completion time. ISAAC'2001, LNCS 2223, 380-389 [Eades, P and Takaoka, T. (Eds.)], Springer-Verlag Berlin Heidelberg 2001.
19. Cheng, T.C.E., and Gupta, M.C. 1989. Survey of scheduling research involving due date determination decision. European Journal of Operational Research 38(1), 156-166.
20. Cheng, T.C.E., Liy, Z. and Yu W., 2001. Scheduling jobs with release dates and deadlines on a batch processing machine. IIE Transaction 33, 685-690.
21. Cheng, T.C.E., and Wang, G., 1998. Batching and scheduling to minimize the makespan on the two-machine flow-shop. IIE Transactions 30, 447-453.
22. Cigolini, R., Perona, M., Portioli, A., Zambelli, T., 2002. A new dynamic look-ahead scheduling procedure for batching machines. Journal of Scheduling 5(2), 185-204.
23. Coffmand, E., and Yannakakis, M. 1990. Batch sizing and job sequencing on a single machine. Annals of Operations Research, 26, 135-147.
24. Deng, X., and Zhang, Y. 1999. Minimizing Mean response time in batch processing system. COCOON'99, LNCS 1637, 231-240 [Asano, T., et al..], Springer-Verlag Berlin Heidelberg 1999.
25. Deng, X., Poon, C.K., and Zhang, Y., 1999. Approximation algorithms in batch processing. ISAAC'99, LNCS, 153-162 [Aggarwal, A., & Pandu Rangan, C.(Eds.)], Springer-Verlag Berlin Heidelberg 1999.
26. Deng, X., Feng, H., Zhang, P, and Zhu, H. 2001. A polynomial time approximation scheme for minimizing total completion time of unbounded batch scheduling. ISAAC'99, LNCS 1741, 153-162 [Aggarwal, A., & Pandu Rangan, C.(Eds.)], Springer-Verlag Berlin Heidelberg 2001.
27. Devpura, A., Fowler, J.W., Carlyle, M.W., and Perez, I., 2000. Minimizing total weighted tardiness on single batch process machine with incompatible job families. *http://www.uni-duisburg.de/FB5/BWL/WI/or2000/sektion10/fowler.pdf* **[**Master Thesis of Perez (1999), Arizona State University, Tempe Arizona**]**.
28. Dobson, G., and Nambimadom, R.S., 2001. The batch loading and scheduling problem. Operations Research 49 (1), 52-65.
29. Dobson, G., and Nambimadom, R.S., 1994. The batch loading and scheduling problem. Working paper No. QM 92-03, Wm. E. Simon school of business administration, University of Rochestor, Rochestor, NY, 14627-0100.
30. Drexl, A., and Kimms, A., 1997. Lot sizing and scheduling – survey and extensions. European Journal of Operational Research 99, 221-235.

31. Dupont, L. and Dhaenens-Flipo, C., 2002. Minimizing the makespan on a batch machine with non-identical job sizes: an exact procedure. Computers and Operations Research 29, 807-819.
32. Dupont, L. and Jolai, G.F., 1997a. An efficient heuristic for minimizing mean flow time on a single batch processing machine. Proceeding (CD ROM) of the second international Franch-Quebec Congress of Industrial Engineering, Albi, France. Paper No. 36.
33. Dupont, L. and Jolai, G.F., 1997c. A Branch and bound algorithm for minimizing mean flow time on a single batch processing machine. International Journal of Industrial Engineering 4 (3), 197-203.
34. Duenyas, I. And Neale, J.J. 1997. Fundamentals of Database Systems. Annals of Operations research, 70, 191-220.
35. Elmasri, R. and Navathe, S.B., 1999. *Fundamentals of Database Systems,* Benjamin/Cummings, 3rd Ed.
36. Fanti, M.P., Maione, B., Piscitelli, G. and Turchiano, B., 1996. Heuristic scheduling of jobs on a multi-product batch processing machine. International Journal of Production Research 34 (8), 2163-2186.
37. Fisher, M.L., Jaikumar, R., and Wassenhove, L.N., 1986. A multiple adjustment procedure for the generalized assignment problem. Management Science 32, 1095-1103.
38. Fowler, J.W., Hogg, G.L., and Phillips, D.T., 1992. Control of multi product bulk service diffusion/oxidation processes. IIE Transactions 24, 84-96.
39. Fowler, J.W., Hogg, G.L., and Phillips, D.T. 2000. Control of multi product bulk service diffusion/oxidation processes. Part 2: multiple servers. IIE Transactions 32, 167-176.
40. Fowler, J.W., Phillips, D.T., AND Hogg, G.L., 1992. Real time control of multiproduct bulk service semiconductor manufacturing processes. IEEE Transactions on Semiconductor Manufacturing, 5(2), 158-163.
41. Fowler, J.W., Phojanammongkolkij, N., Cochran, J.K. and Montgomery, D.C. 2002. Optimal batching in a wafer fabrication facility using a multiprodut G/G/c model with batch processing. International Journal of Production Research, 40(2), 275-292.
42. Glassey, C.R., and Weng, W.W., 1991. Dynamic batching heuristic for simultaneous processing. IEEE Transactions on Semiconductor Manufacturing 4 (2), 77-82.
43. Gordon, V., Proth, J.M., and Chu, C., 2002. A survey of the state-of-the-art of common due date assignment and scheduling research. European Journal of Operational Research 139, 1-25.
44. Gurnani, H., Anupindi, R., and Akella R. 1991. Control of Batch Processing Systems. Proceedings of the 1991 IEEE International Conference on Robatics and Automation, Sacramento, Califirnia, April 1991.
45. Hochbaum, D.S. and Landy, D., 1997. Scheduling semiconductor burn-in operations to minimize total flow time. Operations Research 45, 874-885.
46. Hochbaum, D. and Landy, D., 1994a. Scheduling with batching: minimizing the weighted number of tardy jobs. Operations Research Letters 16, 79-86.
47. Huang, S.-C, and Lin, J.T. 1998. An interactive scheduler for a wafer probe centre in semiconductor manufacturing. International Journal of Production Research, 36(7), 1883-1900.
48. Hung, Yi-Feng, 1998. Scheduling of mask shop E-beam writers. IEEE Transactions on Semiconductor Manufacturing 11 (1), 165-172.
49. Ikura, Y., and Gimple, M., 1986. Scheduling algorithms for a single batch processing machine. Operations Research Letters 5, 61-65.
50. Jolai, G.F., and Dupont, L., 1998. Minimizing mean flow time criteria on a single batch processing machine with non-identical job sizes. International Journal of Production Economics 55, 273-280.
51. Kempf. K.G., Uzsoy, R., and Wang C.S., 1998. Scheduling a single batch processing machine with secondary resource constraints. Journal of Manufacturing Systems 17 (1), 37-51.
52. Kim, H.-U., Kim, Y.-D. and Kim, J.-G., 2000. Batching and scheduling at a batch processing workstation in a semiconductor fabrication facility producing multiple product types with distinct due dates. Proceedings of the International Conference on Modeling and Analysis of Semiconductor Manufacturing , 151-156.
53. Kim, Y.-D., Lee, D.-H., and Kim, J.-U. 1998. A Simulation study of on lot release control, Mask scheduling and batch scheduling in semiconductor wafer fabrication facilities. Journal of Manufacturing Systems, 17(2),107-117.
54. Koole, G., and Righter, R. 2001. A stochastic batching and scheduling problem. Probability in the Engineering and Informational Science.
55. Lee, C.-Y, and Uzsoy, R., 1999. Minimizing makespan on a single batch processing machine with dynamic job arrivals. International Journal of Production Research 37 (1), 219-236.
56. Lee, C.-Y, and Uzsoy, R., 1992. A new dynamic programming algorithm for the parallel machine total weighted completion time problem. Operations Research Letters 11, 73-75.
57. Lee, C.-Y., Uzsoy, R., and Martin-Vego, L.A., 1992. Efficient algorithms for scheduling semiconductor burn-in operations. Operations Research 40 (4), 764-775.
58. Li, C.L., and Lee, C.-Y., 1997. Scheduling with agreeable release times and due dates on a batch processing machine. European Journal of Operational Research 96, 564-569.

59. Liu, Z. and Yu, W., 2000. Scheduling one batch processor subject to job release dates. Discrete Applied Mathematics 105, 129-136.
60. Mason, S.J., Fowler, J.W., and Carlyle, W.M., 2002. A modified shifting bottleneck heuristic for minimizing the total weighted tardiness in complex job shops. Journal of Scheduling 5 (3), 247-262.
61. Mathirajan, M., 2000. Heuristic scheduling algorithms for parallel heterogeneous batch processors. PhD dissertation, Indian Institute of Science, Bangalore, India.
62. Mehta, S.V., and Uzsoy, R., 1998. Minimizing total tardiness on a batch processing machine with incompatible job families. IIE Transaction 30, 165-178.
63. Neale, J.J. and Duenyas, I., 2000. Control of manufacturing networks which contain a batch processing machine. IIE Transactions 32, 1027-1041.
64. Neufville, R.D. 1990. Applied Systems Analysis: Engineering Planning and Techmolgy Management. McGraw-Hill Publishing Company.
65. Neuts, M.F., 1967. A general class of bulk queues with poisson input. Annals of Mathematical Statistics 38, 759-770.
66. Oey, K. and Mason, S.J., 2001. Scheduling batch processing machines in complex job shops. Proceedings of the 2001 Winter Simulation Conference, 1200-1207.
67. Pinedo, M., 1995. Scheduling: theory and systems, Prentice Hall, Englewood Cliffs, New Jersey.
68. Poon, C.K. and Zhang, P., 2000. Minimizing makespan in batch machine scheduling. D.T. Lee and S.-H. Teng (Eds.): ISAAC 2000, LNCS 1969, 386-397.
69. Potts , C.N., Strusevich, V.A., Tautenhahn, T., 2001. Scheduling batches with simultaneous job processing for two-machine shop problems. Journal of Scheduling 4 (1), 25-51.
70. Potts, C.N., and Kovalyov, M.Y., 2000. Scheduling with batching : A review. European Journal of Operational Research 120, 228-249.
71. Potts, C.N., and Van Wassenhove, 1992. Integrating scheduling with batching and lot-sizing: A review of algorithms and complexity. Journal of Operational Research Society 43 (5), 395-406.
72. Qi, X., and Tu, F., 1999, Earliness and tardiness scheduling problems on a batch processor. Discrete Applied Mathematics, 131-145.
73. Ram, B., and Patel, G. 1998. Modeling Furnace operations using simulation and heuristics. Proceedings of the 1998 winter simulation conference.
74. Robinson, J.K., Fowler, J.W., and Bard, J.F., 1995. The use of upstream and downstream information in scheduling batch operations. International Journal of Production Research 33 (7), 1849-1869.
75. Rosen, S.L., Geist, C.A., Finke, D.A., Nanda, J. and Barton, R.R. 2001. Graphical methods for robust design of a semiconductor burn-in process. Proceedings of the 2001 winter simulation conference.
76. Sen, T., and Gupta, S.K. 1984. A state-of-art survey of static scheduling research involving due-dates. Omega, International Journal of Management Science 12, 63-76.
77. Silver, E.A., and Meal. H.C., 1973. A heuristic for selecting lot size quantities for the case of a deterministic time varying demand rate and discrete opportunities for replenishment. Production and Inventory Management 14, 67-74.
78. Skinner, G., and Mason, S.J., 2002. A genetic algorithm for scheduling parallel batch processing machines. Proceedings of the International Conference on Modeling and Analysis of Semiconductor Manufacturing, 270-275.
79. Solomon, L., Fowler, J.W., Pfund, M., and Jensen, P.H. 2002. The inclusion of future arrivals and downstream setups into wafer fab batch process decisions. Journal of Electronics Manufacturing, 11(2), 149-159.
80. Sox, C.R., Jackson, P.L., Bowman, A., and Muckstadt J.A., 1999. A review of the stochastic lot scheduling problem. International Journal of Production Economics 62, 181-200.
81. Sung, C.S. and Choung, Y.I., 2000. Minimizing makespan on a single burn-in oven in semiconductor manufacturing. European Journal of Operational Research 120, 559-574.
82. Sung, C.S. and Choung, Y.I. 1999. A neural network approach for batching decisions in wafer fabrication. International Journal of Production Research, 37(13), 3101-3114.
83. Sung C.S. and Kim, Y.H., 2002. Minimizing makespan in a two-machine flow-shop with dynamic arrivals allowed. Computers and Operations Research 29, 275-294.
84. Sung, C.S. and Min, J.I., 2001. Scheduling in a two-machine flowshop with batch processing machine(s) for earliness/tardiness measure under a common due date. European Journal of Operational Research 131, 95-106.
85. Sung, C.S., and Yoon, S.H., 1997. Minimizing maximum completion time in a two-batch-processing-machine flow shops with dynamic arrivals allowed. Engineering Optimization 28 (3), 231-243.
86. Sung, C.S., Choung, Y.I. and Fowler, J., 2002a. Heuristic algorithm for minimizing earliness-tardniess on a singale burn-in oven in semiconductor manufacturing. Proceedings of the International Conference on Modeling and Analysis of Semiconductor Manufacturing, 217-222.

87. Sung, C.S., Choung, Y.I., Kong, J.M., and Kim, Y.H., 2002b. Minimizing makespan on a single burn-in oven with job families and dynamic job arrivals. Computers and Operations Research 29, 995-1007.
88. Sung, C.S., Kim, Y.H., and Yoon, S.H., 2000. A problem reduction and decomposition approach for scheduling for a flow shop of batch processing machines. European Journal of Operational Research 121, 179-192.
89. Suresh, V. and Chaudhuri, D. 1993. Dynamic scheduling – A survey of research. International Journal of Production Economics, 32, 53-63.
90. Uzsoy, R., 1995. Scheduling batch processing machine with incompatible job families. International Journal of Production Research 33 (10), 2685-2708.
91. Uzsoy, R., 1994. Scheduling a single batch processing machine with non-identical job sizes. International Journal of Production Research 32 (7), 1615-1635.
92. Uzsoy, R., and Yang, Y., 1997. Minimizing total weighted completion time on a single batch processing machine. Production and Operations Management 6 (1), 57-73.
93. Uzsoy, R., Lee, C.-Y. and Martin-Vega, L.A., 1992. Scheduling Semiconductor Test Operations: Minimizing Maximum Lateness and Number of Tardy Jobs on a Single Machine. Naval Research Logistics 39, 369-388.
94. Uzsoy, R., C.-Y. Lee, and L.A. Martin-Vega. 1992. A Review of Production Planning and Scheduling Models in the Semiconductor Industry, Part I : System Characteristics, Performance Evaluation and Production Planning. IIE Transactions, 24(4), 47-60.
95. Uzsoy, R., C.-Y. Lee, and L.A. Martin-Vega. 1994. A Review of Production Planning and Scheduling Models in the Semiconductor Industry, Part II : Shop Floor Control. IIE Transactions on Scheduling and Logistics, 26(5), 44-55.
96. Uzsoy, R., Martin-Vega, L.A., Lee, C.-Y. and Leonard, P.A., 1991. Production Scheduling Algorithms for a Semiconductor Test Facility. IEEE Transactions on Semiconductor Manufacturing 4 (4), 270-280.
97. Vepsalainen, A., and Morton, T.E., 1987. Priority rules and lead time estimation for job-shop scheduling with weighted tardiness costs. Management Science 33 (8), 1035-1047.
98. Wang, C.S. and Uzsoy, R., 2002, A genetic algorithms to minimize lateness on a batch processing machine. Computers and Operations Research 29, 1621-1640.
99. Webster, S., and Baker, K.R., 1995. Scheduling groups of jobs on a single machine. Operations Research 43(4), 692-703.
100. Weng, W.W., and Leachman, R.C., 1993. An improved methodology for real-time production decisions at batch process workstations. IEEE Transactions on Semiconductor Manufacturing 6 (3), 219-225.
101. Zee, D.J. van der, Van Harten, A., and Schuur, P.C., 2001. On-line scheduling of multi-server batch operations. IIE Transactions 33, 569-586.
102. Zee, D.J. van der, 2000. Look-ahead strategies for controlling batch operations in industry-overview, comparison and exploration. Proceedings of the 2000 Winter Simulation Conference, 1364-1373.
103. Zee, D.J. van der, Van Harten, A., and Schuur, P.C., 1997. Dynamic job assignment heuristics for multi-server batch operations – A cost based approach. International Journal of Production Research 35 (11), 3063-3093.
104. Zhang, G., Cai, X., Lee, C.-Y., and Wong, C.K., 2001a. Minimizing makespan on a single batch processing machine with non-identical job sizes. Naval Research Logistics 48, 226-240.
105. Zhang, G., Cai, X., and Wong, C.K., 2001b. On-line algorithms for minimizing makespan on batch processing machines. Naval Research Logistics 48, 241-258.